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What Can Fecal Pellets Tell Us About Cryptic Drywood Termites (Isoptera: Kalotermitidae)?

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ABSTRACT

Drywood termites (Isoptera: Kalotermitidae) are serious economic pests of both plants and seasoned wood (furniture, wood frame structures). Currently, five species of kalotermitids are known to occur in the Hawaiian Islands: *Neotermes connexus, Incisitermes immigrans, Incisitermes minor*, *Cryptotermes brevis,* and *Cryptotermes cynocephalis*. These termites are difficult to detect and observe due to their cryptic habitat. Unlike termites that nest in the soil, and forage outward for wood, drywood termites nest directly in their food source. Often, the only outward sign of termite infestation is the presence of small fecal pellets, expelled from the gallery system through small holes in the wood surface. This report reviews recent research indicating that these fecal pellets may be a valuable source of information on the biology of these cryptic insects, including the identity of the termite species, the relative cellulose content of the food source, and the size and even the age of the population.

KEYWORDS: *Cryptotermes, Incisitermes*, Kalotermitidae, termite biology

1. INTRODUCTION

Unlike subterranean termites (Family Rhinotermitidae), which nest in the soil and tunnel outward to find wood to feed upon, drywood termites (Family Kalotermitidae) nest directly within their food source (Abe 1987). Since their colonies are smaller than subterranean termites, usually numbering only a few hundred to a few thousand individuals rather than the thousands or millions found in subterranean termite colonies, damage occurs more slowly. However, their cryptic nature and the difficulty of detecting these wood-destroying insects can lead to severe damage to wooden objects and structures. Each individual drywood termite colony is founded by a male and female alate (winged reproductives) excavating a nesting cavity in the wood surface, and both multiple termite colonies within single boards or wooden objects and large colonies with gallery systems extending through the joints between boards into multiple timbers are common scenarios (Grace *et al.* 2009, Woodrow *et al.* 2006).

In Hawaii, the drywood termites *Neotermes connexus*, *Incisitermes immigrans* and *Cryptotermes brevis* predate western colonization (Zimmerman 1948, Grace *et al.* 2002). Both *N. connexus* and *I. immigrans* typically infest portions of living plants (or stumps or fallen wood in the case of *N. connexus*), although *I. immigrans* is occasionally found in buildings. *Neotermes connexus* is often found at higher elevations, such as heavily infested tea plants recently observed by the author above Kapaa, Kauai, but can be found in wet regions extending to the coastline (Woodrow *et al.* 1999).

Unlike the previous two species, *Cryptotermes brevis*, the West Indian drywood termite, infests seasoned wood almost exclusively. In fact, Hawaii is one of the very few places in the world where this termite has been reported in a living plant (Scheffrahn *et al.* 2000). At present, *C. brevis* is second in importance only to the Formosan subterranean termite, *Coptotermes formosanus*, as a structural pest in the Hawaiian Islands.

The final two drywood termite species currently occurring in Hawaii are fairly recent invaders, and were only discovered in Hawaii during the past decade. *Incisitermes minor*, the most serious drywood termite pest in California, has been found in cabinetry and doors in four homes (two of which were adjacent to each other) in three different locations on the island of Oahu. The most recent occurrence of this pest in November 2008, was in kitchen cabinets in a home in the town of Kaneohe on the eastern side of the island. In the case of the other infestations, almost 10 years ago, swarming termites were reported. It is likely that this termite has been introduced multiple times from the west coast of the continental United States in imported building products.

Cryptotermes cynocephalus, a very common pest of buildings in the Philippines, has been found in dead tree limbs in two nearby locations on the east side of the island of Oahu. Although this species has not yet been found in buildings in Hawaii, it is likely that it was introduced in household effects or shipping materials brought from the Philippines.

Drywood termite control in Hawaii is very dependent upon structural fumigation with sulfuryl flouride (Vikane, Dow AgroSciences). Heat is also effective in killing drywood termites (Woodrow and Grace 1998b), and has been used in Hawaii for termite control in the past (Woodrow and Grace 1997, 1998a). For commercial reasons, this termite control option is not available in Hawaii at the present time, but is used in various regions of the continental United States. Although termites are able to move within their gallery systems in structural wood to escape unfavorable temperatures (Woodrow and Grace 1999), the combination of large space heaters and thermocouples placed into the wood in variety of locations to monitor temperature increase can result in effective, nonchemical, control (Lewis and Haverty 1996, Woodrow and Grace 1998a).

Injection of insecticide into the wood is a common method of controlling small and clearly delimited drywood termite infestations. Care must be taken, however, to inject the insecticide into all gallery systems in the wood, and ideally into multiple locations within each gallery system (i.e., termite colony). This requires drilling quite a few small holes into the wood, and is not an easy task since different gallery systems may occur at different depths in the wood, and single colonies may extend over multiple timbers (Woodrow and Grace 2005, 2007; Woodrow *et al.* 2006; Grace *et al.* 2009). Treatment of the surface of the wood with borate or other preservative solutions is certainly helpful in prevention of initial infestation by termite alates, but even diffusible materials do not penetrate deeply enough beneath the surface to reach existing termite galleries (Grace and Yamamoto 1994), without actually being injected into them.

The cryptic habits of drywood termites make it difficult to study their foraging patterns and social behavior in situ. Non-destructive detection methods such as acoustic emissions detectors have proven helpful in determining the presence or absence of termites in wood

(Scheffrahn *et al.* 1997, Woodrow *et al.* 2006), and the extent of termite infestation in structures (Scheffrahn *et al.* 1993, Thoms 2000). However, these methods largely provide a binary indication of presence/absence (Woodrow *et al.* 2006, Woodrow and Grace 2007), and give no information on the presence of multiple termite colonies or the configuration of termite galleries. At present, the latter information can really only be obtained by destructive sampling - careful dissection of the infested wood to map galleries and their connections. Such dissections have revealed both the presence of multiple colonies in single boards, and extension of single colony gallery systems through multiple boards (Fig. 1) (Woodrow *et al.* 2006, Grace *et al.* 2009).

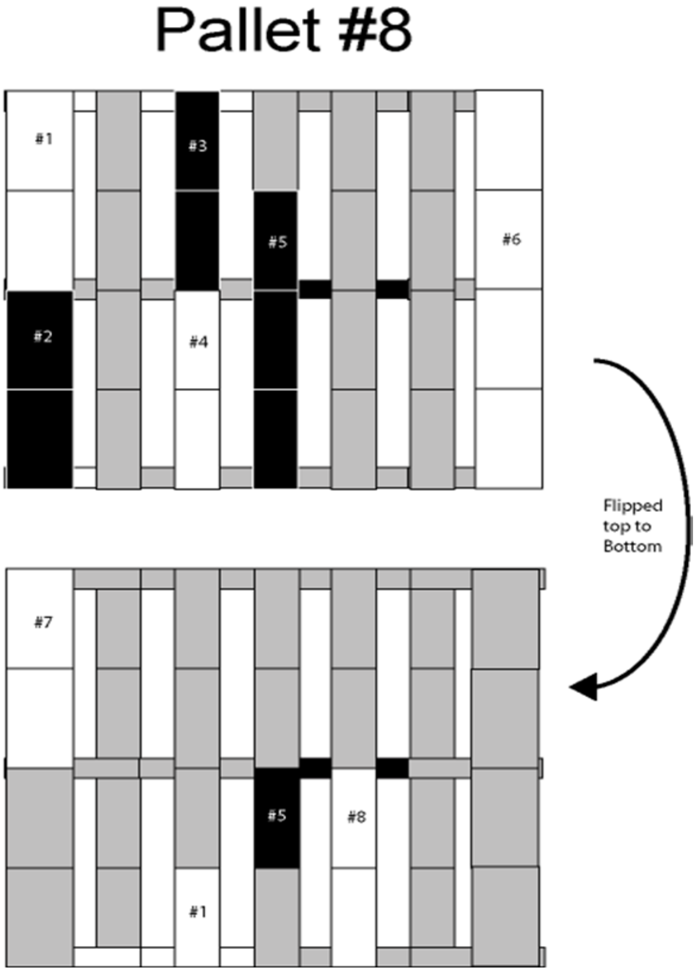

Figure 1: Multiple *Cryptotermes brevis* termite colonies, indicated by different numbers, occupy a single hardwood shipping pallet. Colonies may be contained within a single board, or extend into several adjacent boards. Figure redrawn from Woodrow *et al.* 2006.

Unless infested wood is visibly damaged, the only evidence of drywood termite infestation is usually the presence of small fecal pellets, expelled from the termite galleries through small penetrations through the wood surface often called “kick-out holes” in the United States. These lignaceous feces are hard and dry, and sometimes compared to grains of sand. They are generally slightly elongated in shape, and six-sided, due to pressure from the insect’s rectal pads.

The research described in this report was conducted in order to determine whether drywood termite fecal pellets might be a valuable source of information on the biology and/or foraging habits of these cryptic insects. Thus, we approached termite feces in the same manner as a wildlife biologist studies mammal or bird droppings to derive information on community ecology, population structure, animal health and nutrition, and foraging behavior. In part, this report reviews and summarizes work described in greater detail by Haverty *et al.* (2005) and Grace and Yamamoto (2009).

2. EXPERIMENTAL METHODS

2.1 Termite Identity

Cuticular hydrocarbon patterns (the qualitative and quantitative patterns of lipid mixtures in the insect's cuticle) are an accepted tool for termite species determination (Haverty *et al.* 1992). Haverty *et al.* (2000) published the cuticular hydrocarbon patterns of all eight termite species currently known to occur in Hawaii. Although seasonal (Haverty *et al.* 1996) and environmental factors (Woodrow *et al.* 2000) can affect minor quantitative changes in these profiles, the qualitative patterns represent a unique chemical signature for each termite species.

To test the hypothesis that fecal pellets would also carry these species-specific chemical signatures, both termites and fecal pellets were collected from infested wood and vegetation containing all five of the kalotermitid species found in Hawaii: *Neotermes connexus*, *Incisitermes immigrans*, *Incisitermes minor*, *Cryptotermes brevis*, and *Cryptotermes cynocephalis*. Drywood termite nymphs were killed by freezing, then dried in a desiccator before extraction in *n*-hexane. Fecal pellets were separated from wood debris using a set of successively smaller sieves, and hand selection with forceps, and were also extracted in *n*-hexane. Sample preparation, and gas chromatographic-mass spectrometric (GCMS) analyses are described in detail by Haverty *et al.* (1996, 2005) and Woodrow *et al.* (2000). The resulting hydrocarbon profiles from insect cuticle and fecal pellet extractions were compared by cluster analysis, with the percentage of each hydrocarbon as the response variable (Haverty *et al.* 2005).

2.2 Termite Food Utilization and Quality

As described by Grace and Yamamoto (2009), *Cryptotermes brevis* nymphs were collected by careful dissection of infested shipping pallets collected in the vicinity of Pearl Harbor, Hawaii. *Incisitermes immigrans* nymphs were collected from infested branches of *Leucaena leucocephala* (Lamk.) de Wit (Koa Haole, Family Fabaceae) on the Manoa campus of the University of Hawaii.

Individual nymphs (10 with each food source) were held in aerated 15-dram plastic vials with the food source for 8 weeks in an unlighted incubator (28 °C). One to three drops of water were added weekly to the food source. Termites were observed daily for molting activity and mortality, and pellets were collected and weighed weekly. At the conclusion of the 8-week exposure, each food source was dried (90 °C, 24 hrs) and weighed to determine consumption.

Groups of 10 nymphs were held under the same conditions as individuals, with three groups for each food source. Again, the total exposure period was 8 weeks, with pellet collections, observations, and food consumption determined as in the individual assays.

Food sources in each vial were as follows: Whatman No. 2 filter paper (0.14g), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (0.5g), Ponderosa Pine (*Pinus ponderosa* C. Lawson) (0.5g).

2.3 Size and Age of Drywood Termite Infestations

Data on termite food consumption and fecal pellet production were plotted against data on the growth of *Incisitermes minor* colonies from Harvey (1934), and best-fit regression curves generated, using Microsoft Excel and Lotus Freelance software. No data were available on the growth of *C. brevis* or *I. immigrans* colonies, but *I. minor* was considered sufficiently comparable. The resulting equations suggest that both population size and age of the termite colony may be estimated from daily pellet production.

3. RESULTS AND DISCUSSION

As described by Haverty *et al.* (2005), hydrocarbons extracted from drywood termite fecal pellets were qualitatively and quantitatively similar to cuticular extracts; and can be used to determine the termite species responsible without the termites present. Of course, this identification requires comparison to a known termite cuticular hydrocarbon pattern, generated using the same methods. We have subsequently validated this technique by "blind" analysis of fecal pellets collected from structural wood infested by an introduced drywood termite, *C. brevis*, in both Honolulu, Hawaii, and New Orleans, Louisiana (M. I. Haverty, L. J. Nelson and J. K. Grace, unpublished).

The similarity of the hydrocarbon mixtures found in termite feces to those found in the cuticle could result from several different scenarios: termites contacting the pellets in the gallery system, cannibalism or ingestion of exuviae, secretion of hydrocarbons from glands in the mouthparts onto the pellets as they were moved and stored, or deposition of hydrocarbons onto the pellets during passage through the rectum (Haverty *et al.* 2005). The latter explanation is most likely, since the rectum is in fact lined with cuticle.

In the feeding studies with *C. brevis* and *I. immigrans* nymphs, solitary individuals defecated more and produced smaller fecal pellets than nymphs maintained in groups, although the total individual mass of feces produced was similar. As described by Grace and Yamamoto (2009), diet affected feeding, food utilization, and fecal pellet number and mass. Both, consumption and defecation reflected the cellulose and lignin content of the substrate, with less ingestion of cellulose-rich filter paper than wood on a weight basis, but greater utilization of the ingested paper (98%) and less fecal mass. The percentages of the ingested wood utilized (i.e., not excreted) were virtually equivalent for Douglas-fir and pine: 63% and 65% respectively with *C. brevis*, and 71% and 72% with *I. immigrans*. Thus, it is likely that building materials of lower nutritional quality, such as composite materials, might suffer greater damage from termite attack than building products with a higher cellulose content exposed to termites for the same period of time.

Each *I. immigrans* nymph consumed about 0.2 mg of wood each day, while each *C. brevis* nymph consumed slightly less than 0.15 mg of wood per day. On the average, nymphs of both termite species deposited from 0.7 to 1.0 fecal pellets per day, equivalent to a daily average fecal mass of 0.06 mg when fed Douglas-fir, and 0.05 mg when fed pine.

Using these consumption and pellet production data, it is possible to plot wood consumption as a function of termite population size (Fig. 2), and population size as a function of the daily mass of pellets produced (Fig. 3). This latter relationship is particularly interesting, since population size not only provides information on the severity of the termite infestation, but may also provide a means of estimating the age of a particular termite colony. This is a question that is often of interest in assessing liability for termite damages.

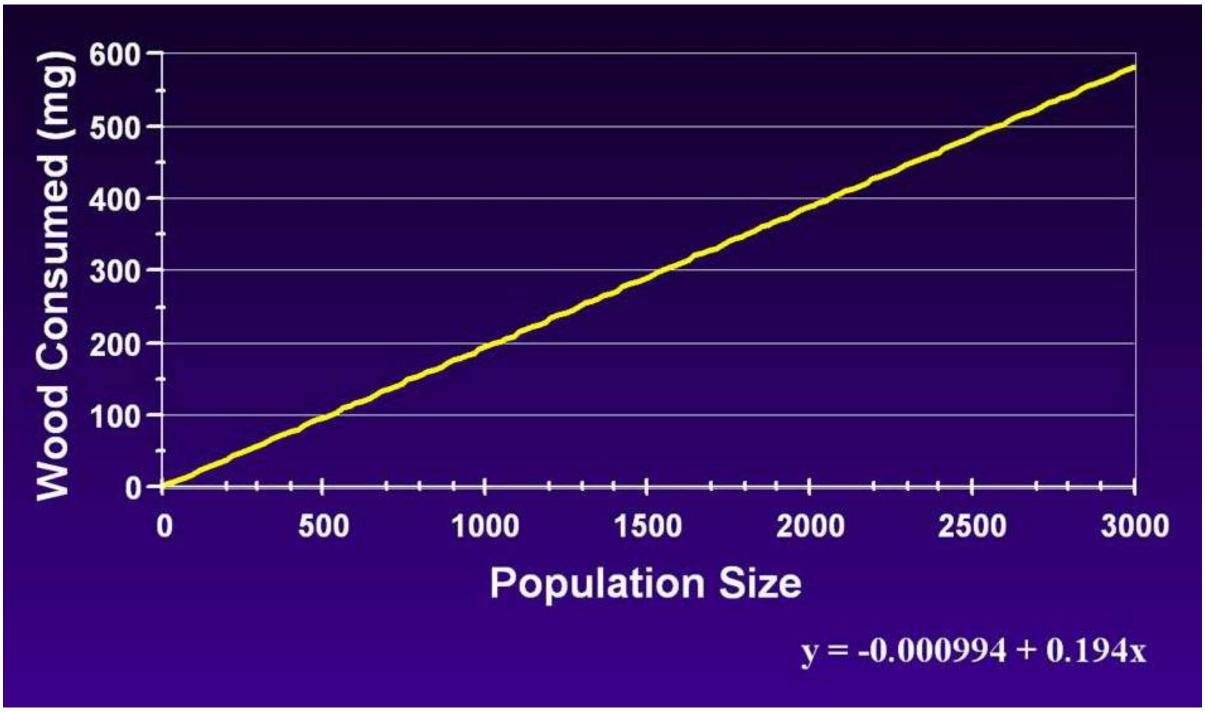

Figure 2: Daily wood consumption of a drywood termite colony in mg (y) as a function of population size (x).

There is very little actual data available on the growth of drywood termite colonies. However, Fig. 4 illustrates the growth of a typical drywood termite colony (*I. minor*) as estimated by Harvey (1934) from field observations and both field and laboratory experiments.

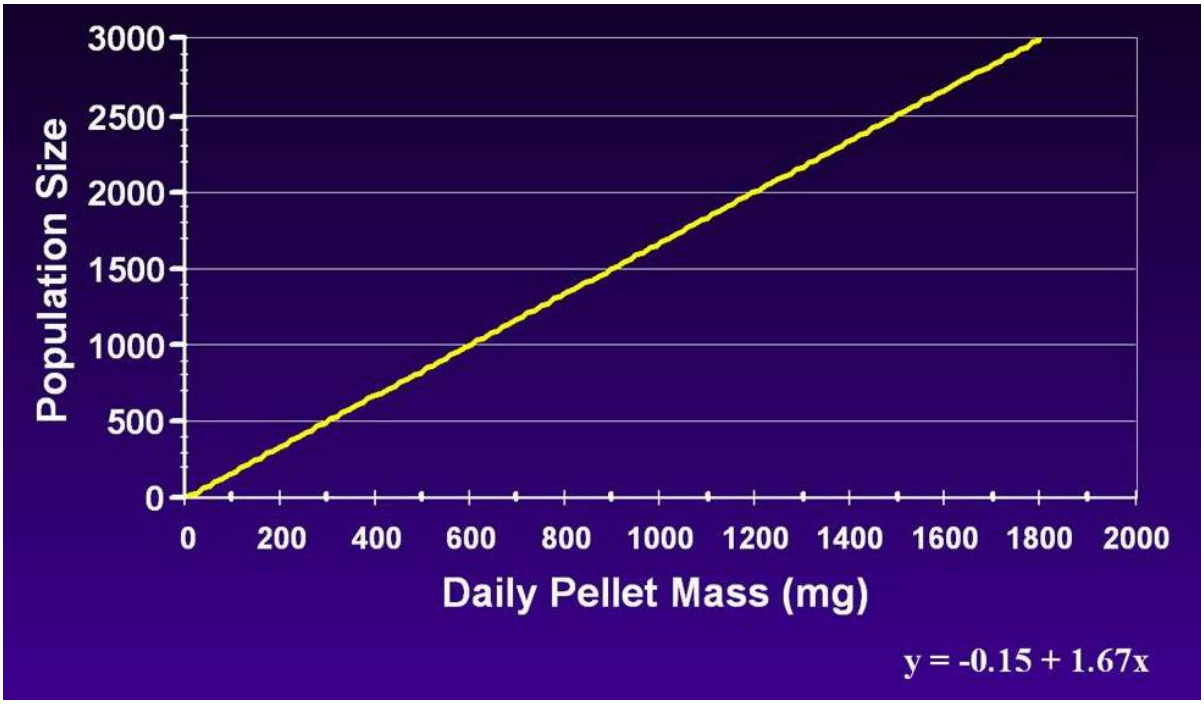

Figure 3: Population size (y) of a drywood termite colony as a function of daily pellet mass in mg (x).

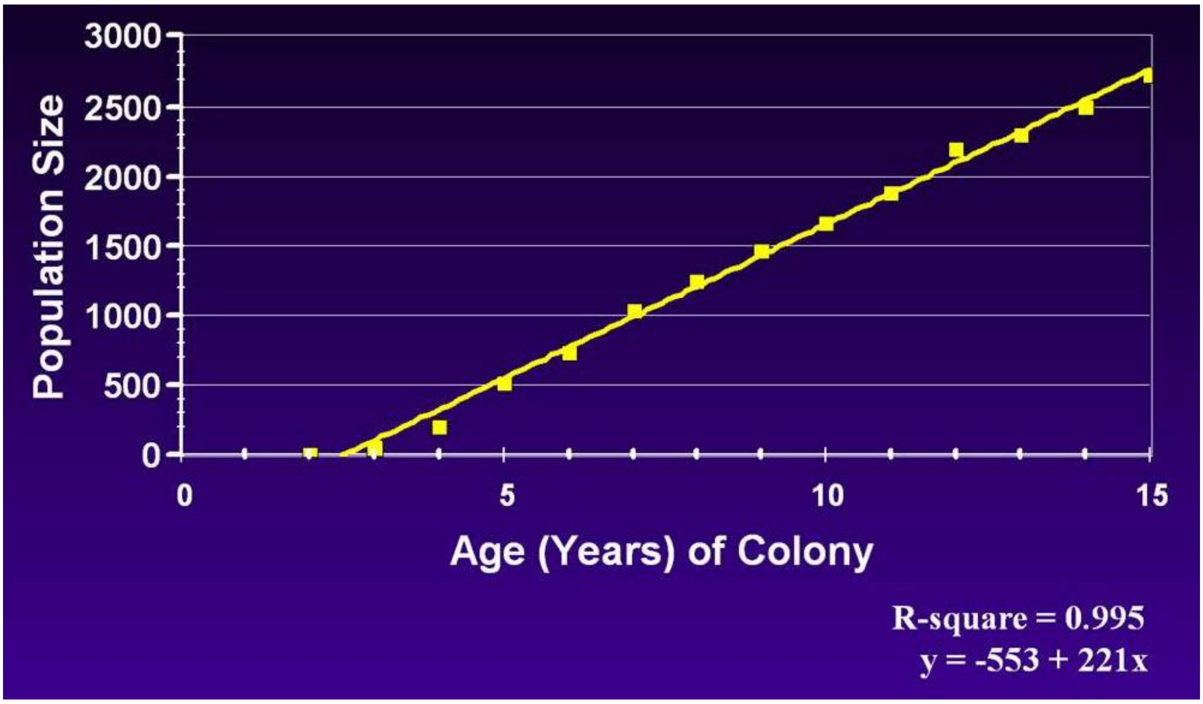

Figure 4: Population size (y) of an *Incisitermes minor* colony as a function of the age in years (x) of the colony (data from Harvey, 1934).

Using the estimated population growth curve from Harvey (1934), and the wood consumption data from Grace and Yamamoto (2009), it is possible to plot daily wood consumption as a function of the age of the termite colony (Fig. 5).

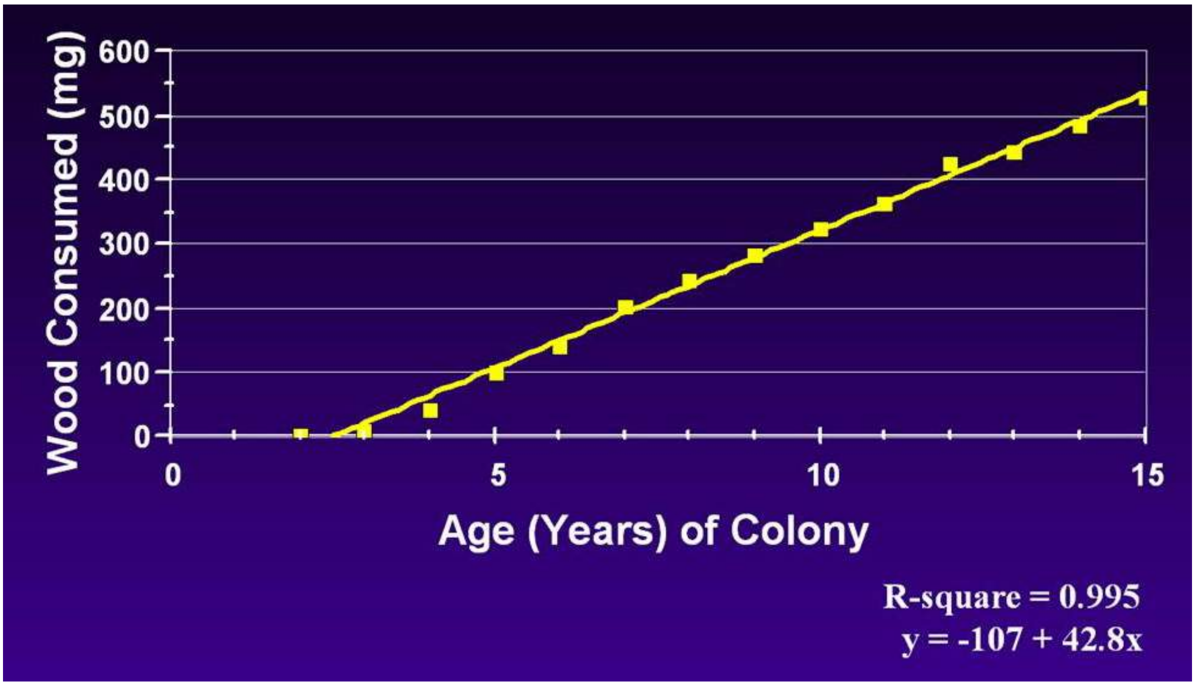

Figure 5: Daily wood consumption in mg (y) of a drywood termite colony as a function of the age in years (x) of the colony.

Finally, again using the data on pellet production, and the relationship between colony age and population size described by Harvey (1934), one can also plot the age of the colony as a function of the daily pellet mass (Fig. 6).

Caution is advised in using the estimation methods presented here, since, again, little data are available on the development of these cryptic and long-lived insects. In addition, this exercise rests on the twin assumptions that (1) one could recover virtually all fecal pellets produced over a given period by a drywood termite colony, and (2) all of the pellets recovered originate either from a single colony or from multiple colonies of approximately the same age. Both of these are questionable assumptions when dealing with termite infestations in a building. However, in a piece of furniture, or even in clearly limited structural infestations where a single termite colony is most likely, pellet collection might actually be accomplished by thorough removal of any visible pellets with a vacuum, placement of plastic sheets (or bags) around the infested wood, and subsequent careful removal of collected pellets over a period of time in order to estimate daily fecal production, and thus termite numbers.

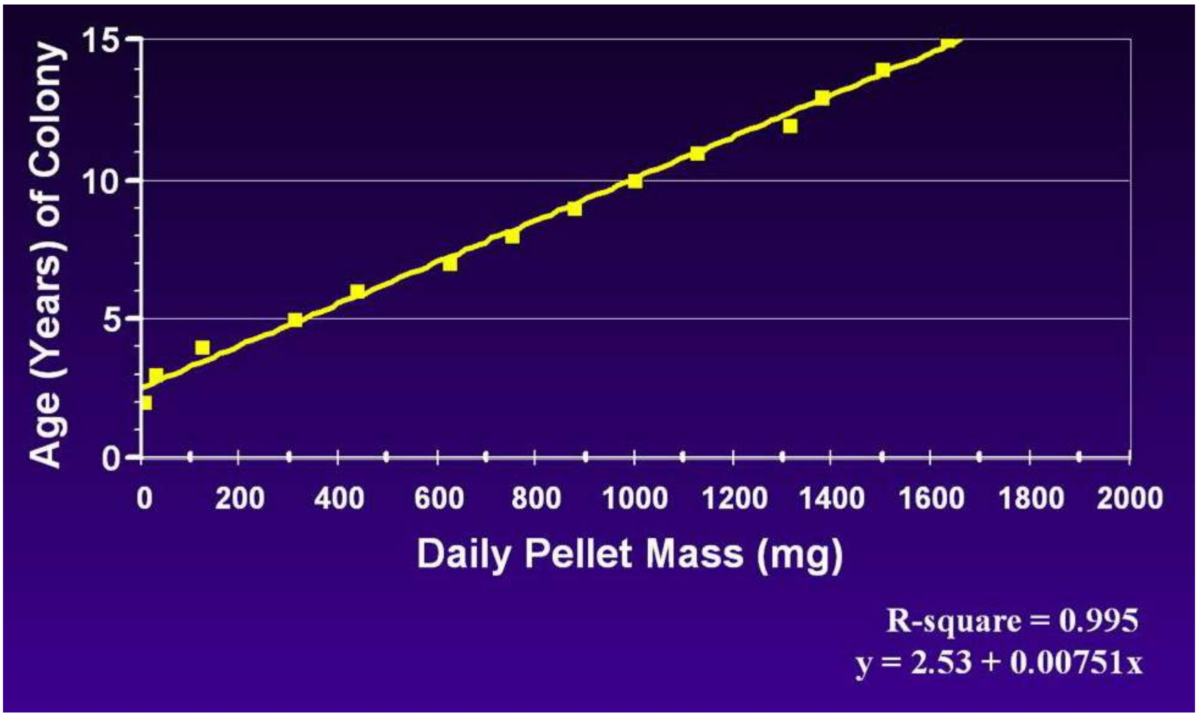

Figure 6: Age in years (y) of a drywood termite colony as a function of daily pellet mass in mg (x).

6. CONCLUSIONS

The results described here demonstrate that fecal pellets may provide a surprising amount of information about cryptic drywood termite species. It is possible to identify the species of termite from analysis of the hydrocarbon mixtures in the feces, and comparison to cuticular hydrocarbon profiles. The size and mass of pellets excreted provides information on the nutritional value of the cellulosic substrate upon which the termites are feeding. With a substrate of high cellulose and low lignin content such as filter paper, fecal pellets are very small, and the mass is much less than that produced by termites feeding on wood. Lastly, collection of fecal pellets offers a means to estimate termite numbers, and potentially even to estimate the age of the drywood termite colony.

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